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Seismic Strengthening of RCC Multi-Storey Building Frames introducing Bracing Systems

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Abstract - *The goal of this study is to strengthen RCC building initially designed and constructed for Seismic Zones II / III but now reclassified under Seismic Zone III / IV respectively because of modified seismic hazard assessments. Therefore, these buildings need to be strengthened introducing vertical steel or damper bracings as retrofit to improve lateral load resistance and structural performances. This study examines the structural performances of G+6, G+12 and G+15 storeyed RCC buildings for seismic zone up gradation. The existing buildings need to strengthen to withstand higher seismic forces because of the areas reclassified from Zone III / II to Zone IV / III respectively. Square-Hollow-Section (SHS) normal bracing members and fluid viscous damper bracing members are introduced in these case studies. For analysis and comparison, we are using the STAAD.Pro and ETABS software packages that contrast the structural behaviors before and after the retrofitting. In comparison to the original design, the results exhibit that the installation of vertical bracing systems greatly improves the safety of beams and columns by increasing their resistance to seismic forces. Mainly the beam column joint moments are drastically reduced thus column and beam designs are becoming safer. The results of these studies demonstrate that the RCC buildings' structural stabilities are significantly increased by the addition of vertical bracing systems making it more earthquake-resistant in the future. This study for high-seismic-risk areas will improve structural engineering's sustainability and safety.*

Key Words: Seismic zone upgrade, Structural retrofitting, Rehabilitation, Increasing rigidity and damping

1. INTRODUCTION

With the increasing frequency and intensity of seismic events, the seismic vulnerability of existing Reinforced Cement Concrete (RCC) buildings has become a major concern. Many structures those were originally designed and constructed under lower seismic classifications are now found to be underprepared due to updated seismic hazard assessments. Particularly in India several regions have been reclassified from Seismic Zone II / III to Zone III / IV respectively, demanding urgent retrofitting interventions to enhance structural safety. One of the most effective and economically viable methods for retrofitting is the introduction of steel bracing or damper bracing systems. These bracings significantly enhance the lateral stiffness and strength of structures, thereby improving their seismic performances. This paper presents a comprehensive study on strengthening of RCC multi-storey buildings, particularly G+6 and G+12 storey buildings using steel bracings and that for G+15 storey building using fluid viscous damper bracings. The study aims to analyze and compare the structural behavior before and after retrofitting under seismic conditions. Mazzolani (Federico M.) introduced the concept of using removable steel Eccentric Braces (EBs) and Buckling Restrained Braces (BRBs) for seismic retrofitting. These systems are not only strong and elastic but also lightweight making them suitable for enhancing the seismic performance of existing structures without requiring major reinforcements. BRBs, in particular, have shown high ductility and stable inelastic response in laboratory tests, providing comprehensive improvements in lateral stiffness, strength and displacement capacity. Studies by D. Aniello, M. Della Corte and G. Mazzolani have reinforced the importance of these bracing systems in effectively reducing storey drifts and ensuring quick installation with minimal disruption to occupants. Similarly, Rajeev Kishan Pandey and Massumi & Tasnimi have demonstrated that steel X-bracings can significantly improve the ductility and energy dissipation capacity of low-ductile RCC frames. Ameena Muhammed A, Ifthana M N, Minnu Kurian, Shilpa Sajil and Merin Mathew (2023) have analyzed the seismic performance of a G+12 RCC residential building in Zones III and IV using ETABS 2018. Six scenarios are studied: unbraced and braced with X, V, Inverted V, K, and Diagonal systems, placed at mid and corner bays. Parameters like lateral displacement, storey drift and base shear have been evaluated. All bracing systems have improved performance, but K-type bracing is the most effective, reducing lateral displacement by 85% and storey drift by 79% in both directions. The study has concluded K-bracing significantly enhances stiffness and seismic resistance. Anes Babu, Dr. Chandan Kumar Patnaikuni, Dr. K.V.G.D. Balaji, and B. Santhosh Kumar (2017) studied the seismic performance of a G+9 RCC building using ETABS 2015 by analyzing three models: without bracing or shear wall, with various steel bracings (X, Chevron, Diagonal, V) and with a shear wall. Evaluated across seismic zones II to V, the study assessed storey displacement, drift, and shear. Results showed Chevron bracing was most effective in zones II and III, while X bracing excelled in zones IV and V. Kasai et. al. (2001), Lee & Taylor (2001), Uetani et. al. (2003), Chen, Li and Cheang (2010) used fluid viscous damper bracings for seismic resistance of tall buildings. Usage of bracing has improved stiffness and reduced drift significantly, proving to be an efficient and economical retrofitting solution.

2. CASE STUDY 1: RETROFITTING A G+6 STOREY RCC BUILDING USING STEEL BRACING

A detailed case study is conducted on a G+6 storey RCC building initially designed for Seismic Zone III, now reclassified under Zone IV. The retrofitting approach involves the use of vertical steel bracing members to enhance lateral load resistance and improves overall structural stability. A comprehensive assessment is conducted including evaluation of structural drawings, material properties (concrete and steel) and site investigations. The study identifies inadequate seismic resistance in the original design.

2.1 Selection and Design of Bracing System

Based on geometry and performance requirements, different configurations such as X-bracing, V-bracing, and K-bracing are introduced. X-bracing is selected for its superior performance in reducing displacement and joint moments. The steel members are designed using STAAD. Pro. Steel bracing members are strategically installed in the structural frames with proper anchorage to the existing RCC components. Modifications such as concrete cutting and specialized connectors ensure a strong interface between the bracing and the original structure. Response spectrum dynamic analysis is conducted. The results exhibit a marked improvement in stiffness, reduction in inter-story drifts, and significant enhancement in beam-column joint safety.

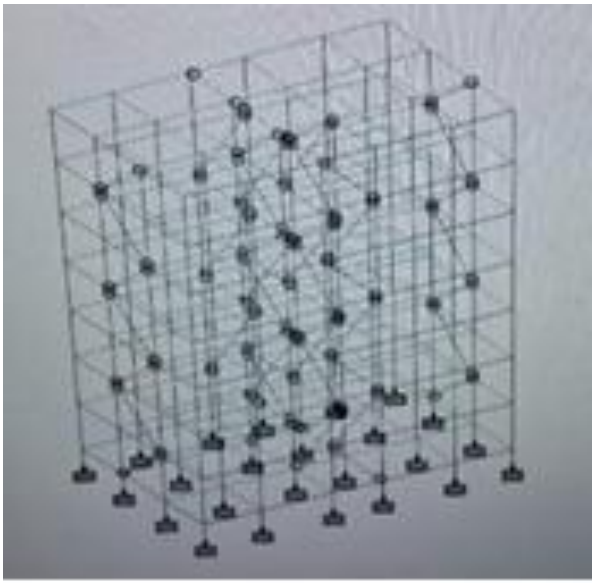

Table 1: Column Forces comparison (in kN-m)

Member No.	Without Bracings				With Bracings			
	Axial Force	Bending Movement	Shear Force	STAAD Design Ast Provide (Zone 3)	Axial Force	Bending Moment	Shear Force	STAAD Design Ast Reqd. (Zone 4)
110	3026	669	288	2.1%	5000	-382	-169	2.1%
109	3030	-683	-298	3.0%	4630	-381	-169	1.2%
117	2846	679	294	2.4%	2835	366	-167	1.8%

Table 2: Beam Forces comparison (in kN-m)

Member No.	Without Bracings			With Bracings		
	Axial Force	Bending Movement	Shear Force	Axial Force	Bending Moment	Shear Force
113	2	418	202	18	299	154
132	2	198	129	-25	84	65
139	4	280	159	-4	185	-110

Fig. 1: Stead picture of G+6 building introducing steel bracing system

3. CASE STUDY 2: RETROFITTING A G+12 STOREY RCC BUILDING USING STEEL BRACING

A G+12 storey reinforced concrete building that was originally designed and constructed considering the parameters of Seismic Zone III, requires retrofitting after the area has been reclassified into Seismic Zone IV due to updated seismic hazard evaluations. To address the increased seismic demands and enhance the structural integrity of the building, vertical steel bracings made of Square Hollow Sections (SHS) are strategically introduced as a retrofitting measure aiming for improving its resistance to lateral seismic forces and overall seismic performance. The primary objective is to enhance the overall structural safety of the building and ensure compliance with the revised seismic design criteria applicable to Zone IV.

3.1 Selection and Design of Bracing System

The structural analysis and design process for the retrofitting measures are performed using STAAD.Pro software, a widely recognized tool for seismic and structural assessment. The vertical steel bracings are meticulously designed and positioned to achieve a substantial reduction in beam-column joint moments as well as to minimize lateral displacements, thereby improving the overall seismic performance and stability of the structure. All bays at ground floors are braced. From first floor level up to roof the peripheral corner bays in both directions and the core well portion are braced.

- The bracing system led to a drastic reduction in joint moments, thus making beams and columns safer.
- Lateral displacements are significantly reduced.

- Stiffness and durability of the building is increased.

The retrofitted structure is now compliant with Zone IV seismic demands.

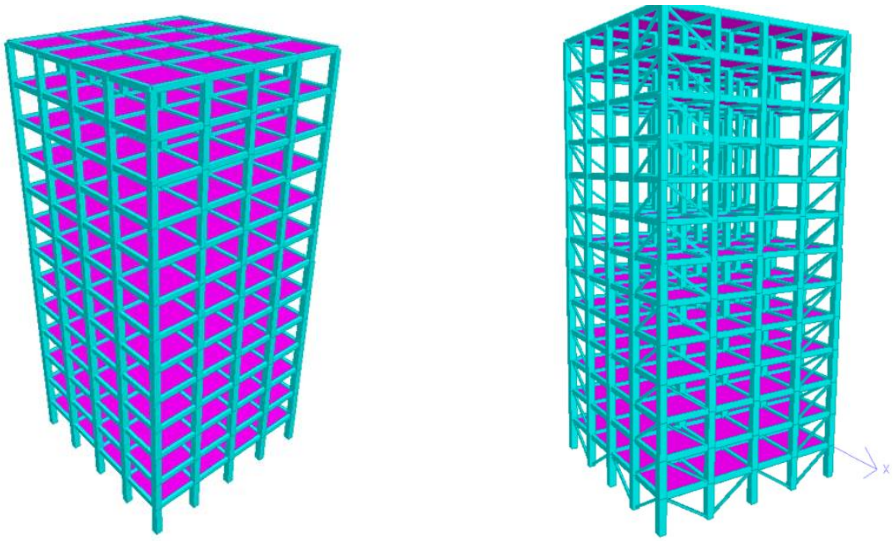

Fig. 2: Staad pictures of the G+12 RCC building without and with steel bracing system

Table 3: Column Forces comparison (in kN-m)

STOREY NUMBER	COLUMN NUMBER	Critical Column Forces					
		Axial Force (KN)		Shear Force (KN)		Moment (KN-m)	
		Normal	Bracing	Normal	Bracing	Normal	Bracing
1	C55	5330	5340	111	41	296	158
	C57	5208	5148	112	41	297	158
	C62	4710	5309	107	45	292	168
	C64	3617	5022	99	41	284	158
7	C439	2737	2781	121	121	190	190
	C441	2687	2651	129	122	204	192
	C446	2360	2516	116	102	184	160
	C448	1831	2482	84	58	133	90

Table 4: Beam Forces comparison (in kN-m)

STOREY NUMBER	BEAM NUMBER	Critical Column Forces					
		Axial Force (KN)		Shear Force (KN)		Moment (KN-m)	
		Normal	Bracing	Normal	Bracing	Normal	Bracing
1	B34	5	44	146	134	192	164
	B35	5	44	146	134	192	164
	B37	12	148	138	118	185	138
	B38	6	143	136	128	180	161
7	B418	4	17	160	161	224	227
	B419	4	17	160	161	224	227
	B420	4	12	167	134	242	231
	B421	7	213	157	125	228	156

4. USAGE OF STEEL BRACING FOR RETROFITTING AND REHABILITATION OF RCC BUILDINGS

So steel bracings are structural elements installed to enhance the lateral stiffness and strength of a building, resisting forces such as wind / seismic activity.

Purposes

1. Prevent buckling in main structural members.
2. Distribute lateral and vertical loads efficiently.
3. Cost-effective, flexible and easy to implement.
4. Improve resistance to seismic and wind forces.
5. Significantly reduce lateral displacements.

Benefits

- **Increased Lateral Stiffness**: Minimizes sway and deflection.
- **Improved Seismic Resistance**: Provides alternate load paths.
- **Reduced Story Drift**: Controls displacement between floors.
- **Economical**: More viable than alternatives like shear walls.

5. CASE STUDY 3: RETROFITTING A G+15 STOREY RCC BUILDING USING VISCOUS DAMPER BRACING

Viscous damper functions on the principle of passive energy dissipation by adding damping of seismic forces in the structure. Previous study on response of structure to earthquakes provided with viscous damper showed that it could reduce storey drift, forces in members that led to less damage to structure enabling it to resist large lateral forces. It is very important to safeguard the structures such as airports, fire department barracks, nuclear power plants, communication centers, hospitals, bus stops, institutions etc. from the earthquakes to reach higher level of safety. By the virtue of damping action of viscous dampers, it reduces forces in the members, enabling provision of smaller cross sections of structural members. This makes the structure safer against seismic action.

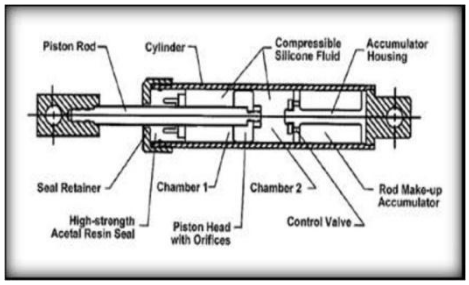

Fig. 3: Fluid Viscous Damper

5.1 Methodology

ETABS is a computer software package for analysis and design of civil structures. It offers an intuitive yet powerful user interface tools to aid the quick and accurate construction of models along with the sophisticated analytical techniques for complex structures. So in the present study three dimensional analyses with the help of ETABS 18 modeling are executed. The work started with modeling and analysis of RCC buildings for two cases:

1. Analysis of the original building.
2. Analysis of that building with effectively using Fluid Viscous Dampers.

An existing 15 storey RCC building is modeled using ETABSs having the total building height of 46.1m including the base and top floor. Concrete grade of M35 and Fe 500 grade steel are assumed. Frame properties such as beams (450mm x 250mm) and columns (400mm x 500mm) are of these dimensions and slab thickness of 125mm. The existing building was designed according to seismic zone II following the IS 1893 (2016): Part-1. Loads such as Dead, Live, Seismic, Wind and default load combinations are applied. Then the fluid viscous dampers are fitted at the four corner side bays of the building and the staircase well areas for retrofitting and analyzed again.

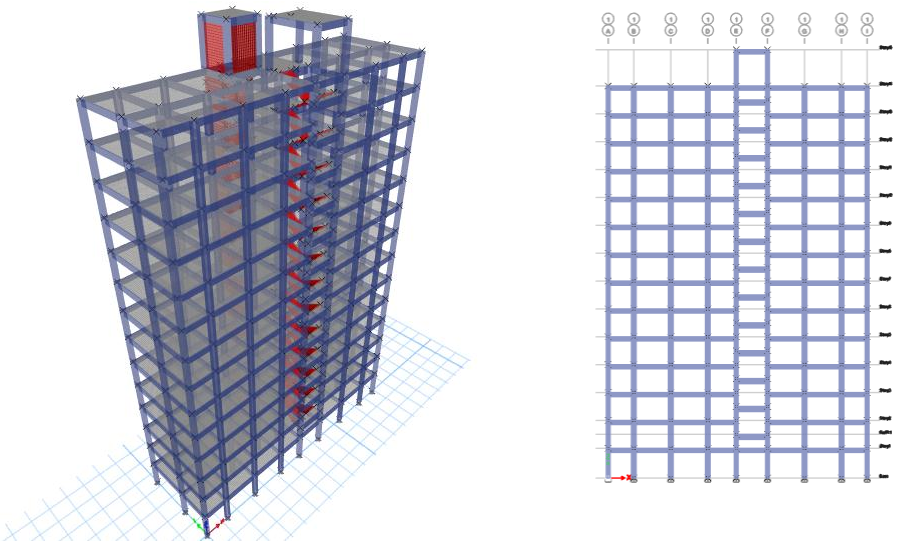

Fig. 4: Without Damper 3d View & Front Elevation View

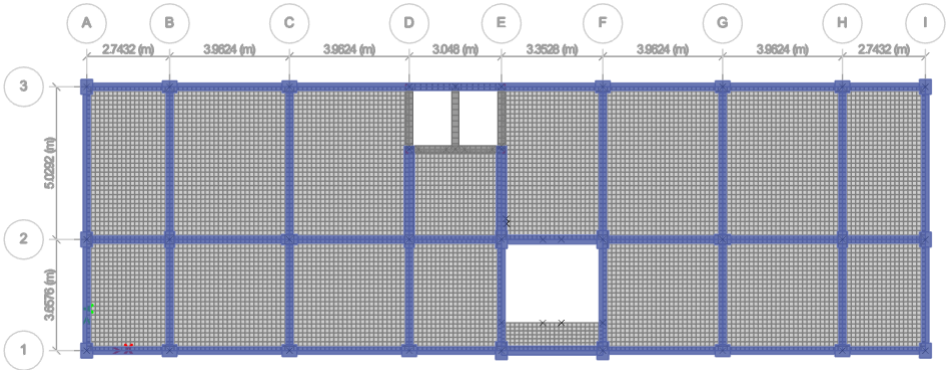

Fig. 5: Without Damper Plan View

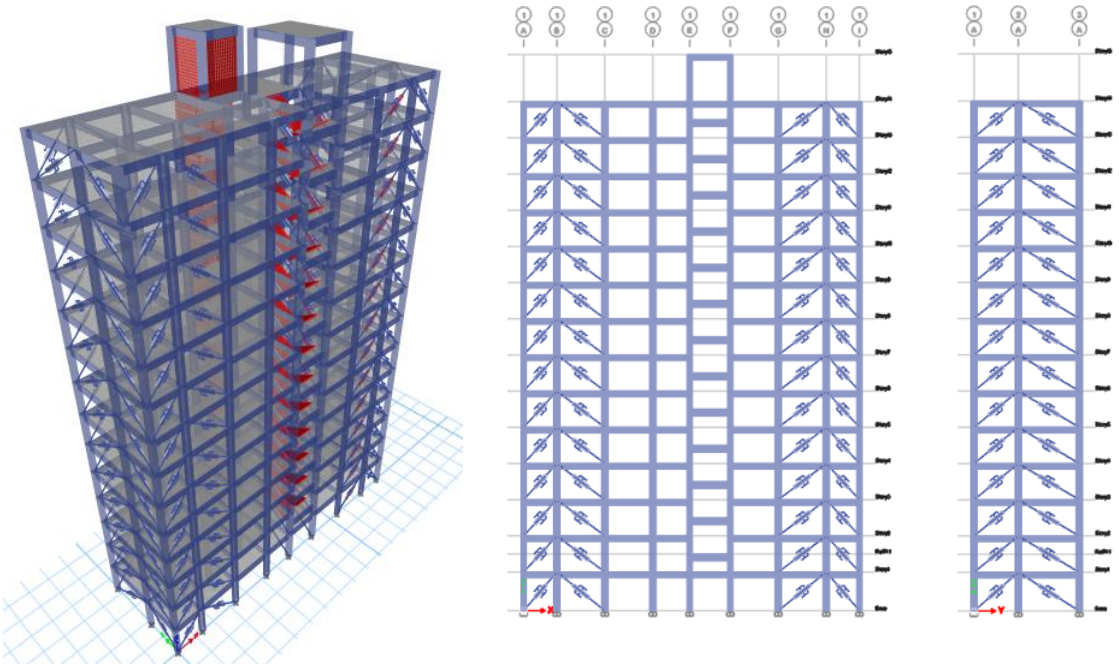

Fig. 6: With Damper 3d View, Front and Side Elevation Views

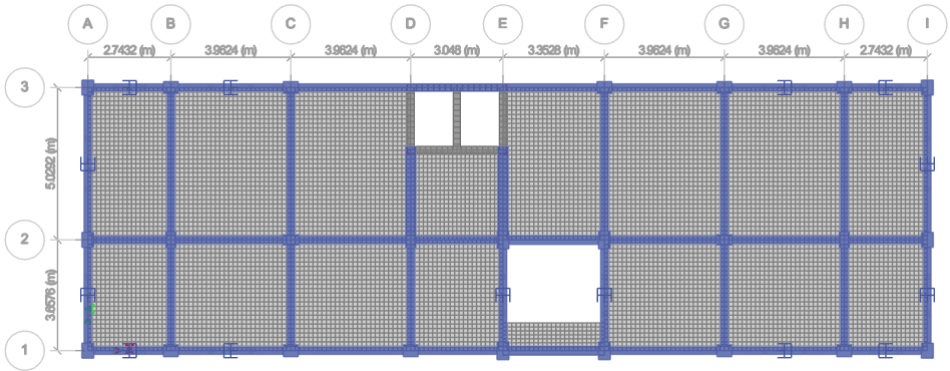

Fig. 7: With Damper Plan View

All the results are obtained successfully completing the seismic analysis of the model, once before applying the seismic retrofitting and another after applying the seismic retrofitting. The aim of the project, as mentioned before, is to analyze only the global behavior without taking into consideration the local behavior of the model. Therefore, there will not be any analysis regarding the connections between the structural elements, material properties and steel design of the elements. Our goal is to strengthen the building under seismic vibration; hence, the focus will be on the frequencies and the displacements of the structure before and after modifying the structure with a retrofitting method. Improving the frequencies and minimizing the displacements will give rise to a more stable structure. It is observed that using damper bracings the lateral storey drifts are controlled satisfactorily.

Table 5 to 8: Critical Column & Beam Member Forces comparisons

Loading Case : Seismic load along X- direction (Seismic X)											
Storey Number	Column Number	Critical Column Forces									
		Axial Force (kN)		Shear Force V2 (kN)		Shear Force V3 (kN)		Moment M2 (kN-m)		Moment M3 (kN-m)	
		Normal	Damper	Normal	Damper	Normal	Damper	Normal	Damper	Normal	Damper
1	C1	857.1	2239.5	58.33	14.46	60.1	6.95	156.9	14.41	145.87	40.19
	C3	900.01	2343.53	25.56	11.37	56.26	5.09	152.89	12.47	69.51	33.81
	C11	1106.66	353.23	85.17	28.07	5.43	2.62	21.4	5.19	169.77	58.18
	C12	2430.42	739.46	61.23	21.12	39.02	3.35	99.69	7.69	144.64	51.02
14	C1	25.56	1.14	10.74	1.69	16.43	0.4	23.53	1.05	16.49	3.16
	C3	14.16	0.65	21.44	0.43	15.68	2.09	22.13	3.01	29.05	1.49
	C11	212.26	111.07	25.15	24.35	60.98	40.37	82.25	55.14	33.9	35.19
	C12	49.97	22.77	52.9	45.71	5.18	1.86	8.93	4.85	67.33	59.1

Loading Case : Seismic load along Y- direction (Seismic Y)											
Storey Number	Column Number	Critical Column Forces									
		Axial Force (kN)		Shear Force V2 (kN)		Shear Force V3 (kN)		Moment M2 (kN-m)		Moment M3 (kN-m)	
		Normal	Damper	Normal	Damper	Normal	Damper	Normal	Damper	Normal	Damper
1	C1	829.53	2518.87	10.36	1.3	12.73	14.42	65.98	51.51	24.09	2.83
	C3	479.04	2461.15	0.73	1.72	11.23	13.75	64.41	50.83	1.57	3.03
	C11	361.26	1229.48	6.38	2.15	95.21	44.33	248.81	111.9	15.47	3.84
	C12	1041.43	1641.52	10.01	1.83	74.4	31.51	242.01	99.6	19.28	2.58
14	C1	27.76	3.42	1.21	3.4	25.89	0.14	38.83	2.31	1.93	4.36
	C3	22.05	5.27	1.71	4.34	30.92	0.82	46.88	3.38	2.27	5.56
	C11	276.19	273.19	28.63	15.99	124.87	77.98	178.33	110.29	40.94	21.84
	C12	108.35	145.2	12.88	1.28	38.66	17.61	61.59	26.73	15.91	1.96

Loading Case : Seismic load along X- direction (Seismic X)					
Storey Number	Beam Number	Critical Beam Forces			
		Shear Force (kN)		Moment (kN-m)	
		Normal	Damper	Normal	Damper
1	B31	166.58	54.27	147.2	49.47
	B26	100.53	18.82	101.47	19.22
	B19	100.09	18.53	101.38	18.95
	B34	93	27.42	67.46	22.28
14	B47	90.68	49.44	85.97	46.14
	B32	71.71	40.74	56.29	39.87
	B29	67.54	36.41	50.27	33.39
	B33	64.02	23.92	40	14.31

Loading Case : Seismic load along Y- direction (Seismic Y)					
Storey Number	Beam Number	Critical Beam Forces			
		Shear Force (kN)		Moment (kN-m)	
		Normal	Damper	Normal	Damper
1	B46	107.17	65.8	14.17	75.65
	B47	106.37	63.37	94.34	61.13
	B15	90.25	25.96	82.32	22.36
	B13	78.72	23.89	72.27	22.1
14	B47	279.88	185.31	105.99	68.51
	B47	129.63	71.98	82.6	81.98
	B12	63.26	34.36	51.04	27.87
	B7	60.71	27.2	36.36	12.23

6. CONCLUSIONS

The combined study of (G+6), (G+12) and (G+15) storey RCC buildings has clearly demonstrated the effectiveness of steel as well as damper bracing systems in seismic retrofitting. Steel bracings provide a significant improvement in structural performance by enhancing lateral load resistance, reducing joint moments and displacements ensuring structural safety in reclassified seismic zones whereas the viscous damper bracings absorb the seismic energy also. Key conclusions include:

- Steel bracing and viscous damper bracing are the effective retrofitting solutions, especially when seismic zoning is up graded.
- Bracing offers improved stiffness, strength and ductility with minimal addition of structural weight.
- Viscous damper bracing system, in particular, yield optimal results in reducing bending moments and lateral displacements.

Both short (G+6) and tall (G+12) & (G+15) storey buildings are benefitted substantially from bracings, making it a universally applicable method in seismic retrofitting strategies.

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